Virtual Reality in Concept Design

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***Abstract*— Modern computer-aided design (CAD) systems and software tools have played a significant role in improving the efficiency of the overall product design process, ensuring geometric accuracy and the exchange of product model data. However, the impact of these technologies is largely restricted to the detailed modeling and engineering analysis that occur during the embodiment design phase. Conceptual design has not benefited from these sophisticated and highly precise software tools to the same degree because the creative activities associated with developing and communicating potential solutions with minimal details is far less formulaic in its implementation. At the early stages of product design the specifications and constraints have not been fully established. The industrial designers and engineers need the freedom to change and modify the product configuration and mechanical behavior to investigate a wide range of alternative solutions. Any CAD system that seeks to support and enhance conceptual design must, therefore, enable natural and haptic modes of human-computer interaction. Recent advancements in high-speed, multi-core computer hardware and virtual reality (VR) technology provide opportunities to link the more fluid processes of creative conceptual design with the rigidly defined tasks of product detailing and engineering analysis. This paper discusses the role that virtual reality can play for concept design module.**

***Keywords*-virtual concept design, virtual reality, modeling and simulation, collision detection, deformable object, B-spline surface.**

I. Introduction

Industrial designers and engineers continue to seek new tools that provide them with the freedom to artistically modify product concepts. The need for a viable VR-based conceptual design tool was realized from several case studies [[1-4]. One key conclusion derived is, that the human-computer interface and related software tools for interacting with the virtual models must be intuitive to the user, provide sensory feedback during design, and mimic the natural way the consumer would interact with the product concepts that are being created. Recent advancements in high-speed, multi-core computer hardware and virtual reality (VR) technology provide opportunities to link the more fluid processes of creative conceptual design with the rigidly defined tasks of product detailing and engineering analysis.

Virtual reality provides real-time interaction with virtual world through several communication methodologies including visual (computer screen or stereoscopic display), tactile (force feedback) and audio (stereo sound) feedback. The overall goal of the virtual reality is to provide a far more natural environment to the user than that is possible by workstations. This can help to enhance the creativity of the user and increase productivity. This environment is especially suitable for free form shape design, wherein an industrial designer or engineer can explore all conceivable options without the constraints imposed by commercial CAD/CAM environments.

II. Bottlenecks in the Use of Virutal Reality

The goal of efficiently integrating sensory-motor functionalities and skills within a VR system poses extraordinary challenges for researchers and engineers in the field. There are many bottlenecks in efficient use of the virtual reality environment. Firstly, the real-time rendering of the complex word during simulation is not advanced enough for industrial applications. In the real word, people can use vision to estimate the distance between objects, and if, these are far or closer to them. The quality of the graphics has improved, of late, but still it has not reached the point of maturity.

The second bottleneck is in the implementation of collision detection algorithms. At present most of the algorithms are limited to particular applications. Most of these algorithms are for rigid bodies. When applied to deformable objects having complex surface, it may not be possible to get real-time interaction. The third bottleneck is in providing physical properties to the virtual models. The sense of touch and force feed mechanisms allow the user, a rich experience in virtual world. However, to simulate the behavior of a real object, the simulation must include object rigidity/strength, mass, friction, surface texture, and heat transfer. Adding these physical characteristics to virtual objects require powerful computing hardware and efficient algorithms.

However, virtual reality development is a fast growing area in computer graphics and engineering. Already, it is being used for training for laparoscopic surgery and games. The interactive design through virtual reality promises to be very intuitive, creative, and cost effective method. With better integration with existing CAD/CAM software, it can provide a very effective way for the industrial designers and engineers to exploit their creativity.

III. State of the Art

Initially, VR-enhanced 3D visualization and analysis systems were used, such as Virtual Design II [5], and ISAAC [6]. In these systems, the product models are initially created in existing 3D CAD systems and then appropriately translated into a VR environment. Such systems only permit designers to visualize and analyze CAD objects in a 3D virtual environment. The COnceptual VIRtual Design System (COVIRDS) is a VR-based CAD modeling environment that allows rapid shape creation by using a bi-modal, voice, and hand tracking interface [7, 8]. It provides parametric and free

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form design modes. Mouse/keyboard interface is replaced with voice recognition and 3D interaction devices. However, it also suffers from fundamental weaknesses including limited recognition capability and difficulty in specifying continuous and complex commands [9].

Many VR-based design system are reported in the literature such as 3-Draw [10], 3DM [11], DesignSpace [12], CDS [13], and CUP [14]. The 3DM allows the designer a better feel for the object's appearance in VR environment through a head mounded display. It however, lacks many other aids and constraints that are necessary to accomplish precise work. All of these techniques provide the designer with real-time interaction with the virtual object. However, each of these VR-based interaction techniques for CAD applications has its own potential and limitations. There is a limitation on the size of the model. When geometries get complex, a time lag sets into the system. Fully immersive design systems can create a more realistic environment but these often tend to make the system infrastructure more complex, cause uncomfortable intrusive viewing problems and make the system computationally expensive.

The Loughborough University Conceptual Interactive Design (LUCID) system [1, 9] was developed to integrate VR-based Human-Computer Interfaces (HCIs) into the design process in order to maximize its interactivity and efficiency so as to provide better support to conceptual design. Weidlich *et al*. [15] focused on integrating VR as a user interface into the process of geometric modeling and detailing. It presents three paths towards a solution: VRAx®, Navigation Interface for Modeling (NavIMode), and Construct|Tool. Most of the preliminary work focused on the user interfaces and the modeling tools for the designers. Robinson *et al*. [16] evaluated Co-Star, an immersive stereoscopic system for cable harness design.

Overall, the results obtained and the positive experience of the participants indicated that 3D immersive design and direct body motion tracked interfaces did provide a very intuitive, easy to use, and useful addition to the technologies available to design engineers. There are more research groups [17, 18] using virtual reality for concept design. Overall there is high demand for a virtual concept design tools in industry.

IV. Haptic Interaction With Virtual Model

In the context of virtual reality applications, haptics is a tactile feedback technology which allows a user to use his/her sense of touch while interacting with a virtual model. By using haptics devices, the user can interact with a virtual model by feeding and receiving information through tactile sensation.Figure 1 shows the user interacting with a virtual model through a haptic device. The haptic sense is usually divided into two main distinct sensory modalities. The first sense is the kinaesthetic sense (motion and force sensing), which includes perception of muscular effort. The second sense is the tactile sense, which provides cutaneous information, related to contact between the skin of the human body and the external environment (pressure, vibration, temperature etc.). These sensory interactions enable the user to perceive physical properties such as rigidity of the model and the surface characteristics of model (roughness etc.).

Figure 1. Haptic interaction with a virtual model through a haptic device (PHANTOM® Omni of SensAble Technologies, 2010).

Commonly, implicit geometry techniques are used to represent clay-like objects proposed by Bloomenthal and Shoemaker [19]. Witkin *et al.* [20] used a physically based particle approach to sample and control implicit surfaces. On the other hand, Raviv and Elber [21] presented an interactive sculpting algorithm that used a set of uniform trivariate B-spline functions as the underlying representations. Knopf and Sangole [22] investigated the *Self Organization Feature Map* (SOFM) as the starting point for haptic interaction. This technique has also been extended for use in surface fitting [23], geometric and visual exploration of numerical data [24]. Pungotra[25] used B-spline surfaces to model objects in virtual reality environment for easy exchange with existing CAD software.

V. Virtual Sculpting

Mathematically, virtual sculpting refers to the dynamic manipulation of virtual object by the user to generate different shapes. Galyean and Hughes [26] presented interactive modeling technique based on the notion of sculpting a solid material. A sculpting tool is controlled by a 3D input device and the material is represented by voxel data. Avila and Sobierajski [27] used a force feedback articulated arm to command a tool. Alternative data structure to represent virtual sculpting has also be proposed such as, voxel-based system [28], and B-spline surfaces [29].

Research is underway to improve computational efficiency and flexibility of haptic sculpting. Multi-resolution surfaces have also been used to reduce computational cost of haptic interaction, particularly of collision detection. Gao and Gibson [30] used multi-resolution B-spline surfaces to reduce the computational cost of haptic interaction. Though the multi-resolution techniques reduce the computation cost of haptic interaction, the haptic force to be fed back to the user is not realistic.

VI. Components of VR Based Concept Design Module

There are three distinct features that any haptics-based concept design module must have. The '*haptic rendering system*' is used for the visualization of the model and the tool. The '*collision detection system*' provides the information regarding the details of the contact of the tool with the model and the tool penetration. The '*physics-based system*' uses the information provided by the collision detection algorithm to determine the deformation of the model(s) and the resultant reactive forces to be fed back to the user. Figure 2 shows the

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schematic representation of a general framework for a haptics-based concept design module.

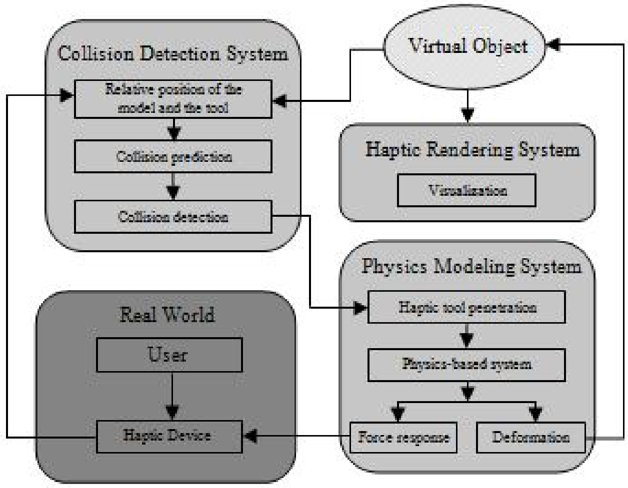

Figure 2. Schematic representation of a haptics-based framework for concept design.

A. Collision Detection

Collision detection enables simulation-based concept design, engineering analysis, assembly, motion planning, medical training and animation. Collision detection is considered a major computational bottleneck in these applications. The goal of collision detection is to automatically report a geometric contact when it is about to occur or has actually occurred. There are many collision detection algorithms proposed by various researchers. Lin and Gottschalk [31] presented a survey on the state of the art in collision detection between geometric models represented by smooth surfaces. Another survey [32] focused more on how the model representation leads to different collision detection algorithms. Pungotra [33] proposed an algorithm that uses the best of parametric representation of surface and efficiency of triangle-triangle intersection test.

B. Physics Based Deformation Modelling

Deformable objects have been widely studied in computer graphics. The deformation of the model can be simulated by a geometric- or physics-based system. Over the years, different modeling techniques have been developed. However, a mass spring damper system, consisting of a set of particles (nodes) connected through a network of springs and dampers can provide reasonable accuracy and speed for real time interaction. The representation of B-spline surfaces in terms of blending matrices facilitates the integration of collision detection and merging of B-spline surfaces with the mass spring system [34].

The *volumetric self-organizing feature map* (VSOFM) [35] is a viable skeletal framework for modeling *realistic* objects that dynamically change shape with time. The sparse point cloud generated on the B-spline surfaces encloses the 3D lattice of the deformable VSOFM, having the required number of nodes attached through springs and dampers. The lattice is allowed to expand to the point cloud. This 3D ordered lattice of the deformable VSOFM maintains the relative connection of neighboring nodes in the mesh as it geometrically transforms into the B-spline surface model shape. The surface nodes are connected to the neighboring surface nodes as well as the interior nodes that lie directly below. In this manner, the points generated on the B-spline surface are assigned as exterior nodes of the mass spring damper mesh representation[36]. Collision detection algorithm determines the region where tool is interacting with the model. This information is used to map the haptic forces to the model.

VII. VR Based Concept Design

The concept design process needs creativity and freedom to innovate and explore alternative solutions [37]. During the concept generation phase a rough idea, which can come from the background research or from a previous design, is expanded into several solution alternatives. Physical product design and production may require major investments and can lead to significant financial implications in the event of a solution not meeting design requirements or specifications. However, these risks can be managed by developing and testing new solutions at the concept stage. The product concepts can be evaluated depending on the design considerations and identified customer needs.

Based on the results of a user study, an industrial designer first outlines requirements of the users. The VR based concept design process starts by defining the user groups and describing the usage of the final concept product. The designer then defines a hypothetical user activity and starts generating more detailed solutions for the products to support this activity. This process includes a description of the basic functions, design specification requirements, functional requirements, ergonomic shape features, constraints, and other important technical attributes.

The evaluation of product concept solutions is one of the critical steps in the concept development process. The target of the evaluation is to make a decision on whether to discontinue the concept, further iterate the concept, or start utilising the concept. Valuable insight into refining the concepts can be gained using evaluation methods involving end-users. An important goal is to identify whether the new product concepts find acceptance amongst the intended target user group. Another goal may be to evaluate the design from a human factors perspective. User evaluation is useful as a tool for iteratively refining the designs based on user feedback in accordance with the concept of user-centred design.

A VR based concept design module can enable an industrial designer to sculpt and validate the concept design in the virtual reality environment. A group of users, fairly representative of the intended user's segment, can evaluate the concept in VR environment. Further design modifications may be guided by different sets of users. These different sets of user may be based on different cultures, geographies, age groups, or medical conditions. These modifications will often deal with a variety of needs that can be fulfilled using innovative but easily implemented changes to the existing generic model.

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Conclusion

In this paper, the role that virtual reality can play in the concept design was introduced. Product designers and engineers require concept design and graphical visualization tools that enable them to quickly modify the shape, style, and functionality of a product concept. The primary role of VR technology is to provide the designer with the ability to intuitively create and manipulate the shape of complex freeform CAD models during concept generation. Several concepts must be developed before the precise and detailed specification of product design is carried out. These concepts must be evaluated for their functionality and tested by various user segments. Prototypes are sometimes built for conceptualization and preliminary validation of the idea which increases the time and the cost of the concept design phase. Instead, virtual reality environment can be used to design, evaluate and test these concepts. A streamlined exchange of information with existing CAD systems for precise and detailed specifications can be carried out. The 3D visualization capabilities and the ability to directly interact with physics-based models suggest that VR environments can play a big role in creative design process.

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